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Granular Activated Carbon Installations

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16. ABSTRACT

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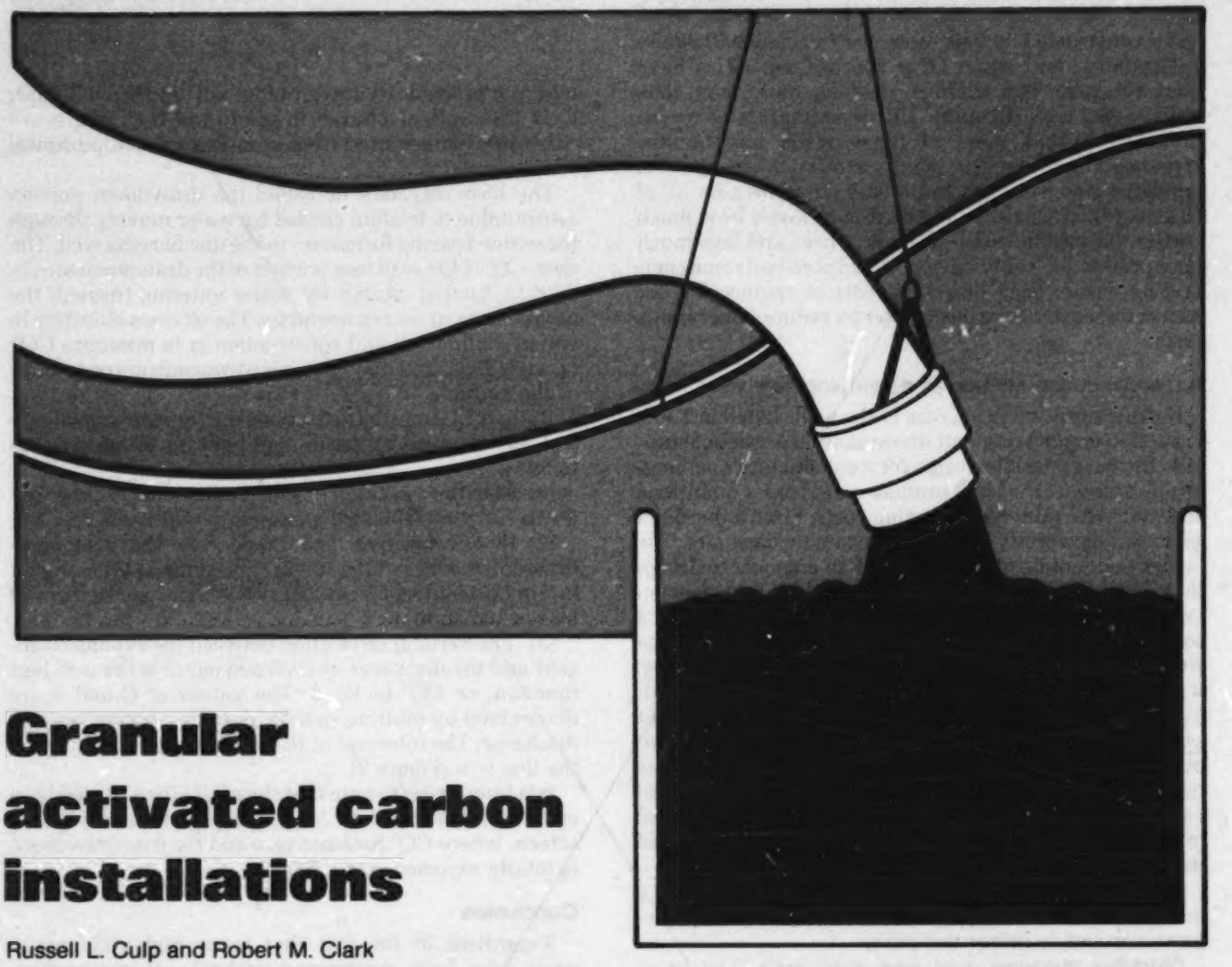


Granular activated carbon installations

Russell L. Culp and Robert M. Clark

This article presents a compilation and summary of design criteria, performance, and cost data from 22 operating municipal and industrial granular activated carbon (GAC) installations that treat water and wastewater or process food and beverage products. Guidance for using this information to estimate costs for GAC treatment of water supplies is provided. In conjunction with previous reports, this article may be used to obtain project-specific cost estimates for water treatment. Although this article does not provide design criteria such as required contact time, probable regeneration frequency, activated carbon reactivation system criteria, or activated carbon transfer guidelines, it presents an approach to determining such design data for water systems.

On Jan. 9, 1978, the US Environmental Protection Agency (USEPA) proposed the use of granular activated carbon (GAC) as a means of treating drinking water. Since that time, much has been written both for and against the use of GAC in this manner. Serious challenges and many questions have been raised regarding the USEPA's cost estimates for GAC use. To respond to some of these questions, the Drinking Water Research Division of the USEPA initiated a carefully designed study to establish cost curves for unit processes within water supply and treatment systems.

Construction and operation and maintenance (O&M) cost curves were developed for 99 different unit processes capable of removing those contaminants included in the National Interim Primary Drinking Water Regulations.[1] Those cost curves were divided into two categories based on treatment capacity: large water treatment systems (flows between 3.7 and 760 ML/d [1 and 200 mgd]) and small water treatment systems (flows between 9.5×10^3 L/d and 3.7 ML/d [2500 gpd and 1 mgd]).[2,3] A computer program for retrieving, updating, and combining the cost data was also developed.[4] During the course of this work, the costs of GAC adsorption and reactivation in municipal water treatment as they relate to the removal of organics from drinking water became a subject of great interest. Therefore, in 1978, the original project was expanded to include a special study of the costs of GAC adsorption and reactivation in potable water treatment. This study consisted of visiting as many GAC installations as possible to gather data on actual operating experiences, particularly the costs of building, operating, and maintaining GAC plants.

The findings of that special study of GAC installations as well as information available on the use of GAC in water treatment are summarized in this article.*

Use of activated carbon in water treatment

Powdered activated carbon (PAC) has been used, without harmful effects, for more than 50 years to remove taste and odor from public water supplies, but GAC has been used by only a few facilities in the United States for removing taste and odor from drinking water. (European water utilities have had considerable experience with GAC installations.) Use of GAC may become more common in the United States because of new information on the occurrence of trace organics in water, the recent regulations limiting the concentration of trihalomethanes in public water supplies, and the possibility of requirements for GAC treatment.

Although the use of GAC in municipal water treatment has been limited, GAC has been used in industrial and municipal wastewater treatment and in various industrial process applications. The specific uses of GAC for these applications are somewhat different from those for water treatment, but much of the information on design and operations should prove useful to water purveyors. In general, the application of GAC adsorption to drinking water treatment is simpler than its application to wastewater treatment. Eighteen of the 22 GAC installations visited were industrial process or municipal wastewater facilities, whereas 4 installations were municipal water treatment plants. Design, operating, performance, and cost information for these installations are summarized in Table 1.

A principal function of the site visits was to collect construction and O&M cost information on GAC installations. Plant records were used to obtain available construction costs, the dates for these costs, and the most recent O&M costs. The basic data are presented in Table 1, but no attempt has been made to update construction or O&M costs to present-day prices or to extrapolate the costs to water treatment plants. However, this article does refer to procedures with which data from existing GAC projects can be adjusted or modified (based on the results of pilot-plant tests of the water to be treated). These data can be used by experienced professionals in making preliminary estimates of costs for future potable water projects involving GAC adsorption and reactivation or replacement.

Municipal wastewater experience. The first plant-scale use of GAC in a municipal wastewater treatment plant was at South Lake Tahoe, Calif., in 1965. This plant has operated continuously since that time and now has more than 15 years of operating experience with a GAC system that has processed more than 45 GL (12 bil gal) of pretreated municipal wastewater. The reclaimed water's chemical oxygen demand (COD) ranges from 10 to 30 mg/L. The South Tahoe installation was a USEPA demonstration plant. For three years, the USEPA funded the collection of complete, detailed plant operating data and cost information.

Other wastewater installations. Water reclamation plants constructed by the Orange County (Calif.) Water District, the Upper Occoquan (Va.) Sewer Authority, and the Tahoe-Truckee Sanitation Agency have the same type of GAC facilities and the same high degree of pretreatment as the South Tahoe plant. All of these plants operate successfully with few GAC system problems. As might be expected with second and third generation designs, these newer plants embody some improvements in the original design, although no major changes or deviations were made.

Although many other successful applications of GAC in advanced waste treatment plants exist, the GAC experience in some advanced waste treatment plants has unfortunately been poor. Failures in advanced waste treatment applications have not stemmed from deficiencies in the basic GAC processes or in organics adsorption and thermal reactivation but rather from mechanical problems.

Operational problems. In discussing the operational problems encountered with GAC systems, it is necessary to distinguish those problems associated specifically with sewage from general problems that might be encountered with any type of GAC system. Many problems with GAC in wastewater treatment will not occur in water purification. For example, in water treatment, few or no problems would be expected with excessive slime growths, hydrogen sulfide gas production, or corrosion from adsorbed organics released during carbon reactivation.

Some of the problems encountered with GAC systems in wastewater treatment include

- Inadequate GAC transfer and feed equipment;
- Undersized slurry and transfer lines;
- Failure to provide for venting air from backwash lines, which destroys filter bottoms and disrupts GAC;
- Failure to house or otherwise protect automatic control systems from the weather;
- Inadequate means for continuous, uniform feed to the furnace, which causes temperature fluctuations, inconsistent reactivation efficiency, and wasted energy;
- Placement of furnace and auxiliary drive motors in areas with high ambient temperature (e.g., above top of furnace); and
- The use of nozzles in filter and carbon contactor bottoms, which produces major failures in carbon systems just as it has for many years in water filtration plants. This use of nozzles is risky.

The common problems associated with wastewater treatment have been the growth of biological organisms in the activated carbon contactors and the development of anaerobic conditions with the production of corrosive hydrogen sulfide. Both of these problems have been successfully circumvented by providing adequate flow through the columns or frequent backwashing. Failure to provide adequate pretreatment has caused columns to clog and mud balls to form and has necessitated more frequent backwashing.

Corrosion has been a problem with some GAC systems. The furnace system, transfer piping, and storage tanks are susceptible components. Many systems require frequent replacement of the rabble arms and teeth and replacement of the hearths every few years. At one installation, titanium- or ceramic-coated rabble teeth were no more resistant to corrosion than stainless-steel

*This paper summarizes a portion of a more detailed document: Granular Activated Carbon Installations. EPA Rept. EPA-600/2-81-177. USEPA, Municipal Environ. Res. Lab., Cincinnati, Ohio (Sept. 1981).

TABLE 1
Summary of GAC system characteristics

Case Number	Owner	Type of Facility	Flow		Pretreatment	Carbon Contactors			Furnace	
						Contact Time	Hydraulic Loading		Rate Capacity	
			ML/d	mgd		min	mm/s	gpm/sq ft	kg carbon/d	lb carbon/d
1	South Tahoe	Municipal wastewater	28	7.5*	Extensive	17	4.4	6.5	2 720	6 000
2	Tahoe-Truckee	Municipal wastewater	18	4.83*	Extensive	20			1 740	3 840
3	Upper Occoquan	Municipal wastewater	57	15.0‡	Extensive	22	5.7	8.4	5 440	12 000
4	American Cyanamid	Chemprocess	76	20.0‡	Extensive	30	5.4	8.0	55 300	122 000
5	Vallejo	Municipal wastewater	49	13.0‡	Moderate	25	4.1	6.0	13 200	29 000
6	Orange County	Secondary effluent	57	15.0*	Extensive	34	3.9	5.8	5 440	12 000
7	Niagara Falls	Municipal with significant industrial	180	48.0‡	Moderate	40	1.1	1.67		
8	Fitchburg**	Municipal with significant industrial	57	15.0‡	Moderate	15	5.4	8.00		
9	Arco Petroleum	Process waters with significant industrial	16	4.32*	Minimal	56	1.2	1.74	3 860	8 500
10	Rhone-Poulenc	Herbicide production wastes	0.6	0.15*	None	87	1.4	2.00	3 860	8 500
11	Reichhold Chemicals	Chemical production wastes	3.8	1.0*	Moderate	100	1.1	1.55	14 700	32 500
12	Stepan Chemicals	Surfactant production wastes	0.06	0.015*	None	500			2 940	6 480
13	Republic Steel	Coke process wastes	3.8	0.95*	Minimal	58–116	1.6–3.1	2.3–4.6	30 800	68 000
14	Leroy	Municipal	3.8	1.0*	Extensive	12			5 440	12 000
15	Manchester	Water supply	150	40.0*	Moderate	14			5 440††	12 000††
16	Passaic Valley‡‡	Water supply	8.3	2.2*	Extensive	8			1 090	2 400
17	Colorado Springs	Secondary effluent	7.6	2.0*	Extensive	17	3.1	4.5	816	1 800
18	Hercules	Chemical production wastes	12	3.25*	Moderate	48	4.5	6.6	15 200	33 600
19	Industrial Sugar	Decoloring sugar			Minimal	1080			5 440	12 000
20	Hopewell	Water supply	11	3.0*	Moderate		1.4	2.0	None	None
21	Davenport	Water supply	110	30.0*	Moderate	7.5	1.4	2.0	None	None
22	Spreckles Sugar	Sugar thick juice			None	20			6 800	15 000

*Maximum flow
†Not available
‡Average flow
§Data not collected
**Facility under construction
††Fluidized bed
‡‡GAC test facility

rabble teeth. In one case, the corrosion problem in the furnace was solved by eliminating the use of auxiliary steam during reactivation. In another, corrosion was linked to fluctuating temperatures in the hearths caused by irregular feed to the furnace and frequent startup and shutdown. In several industrial applications, the wastewater itself has been highly corrosive. In these cases, the contactors have been subject to corrosion; the linings in the columns have been replaced on a regular basis. Water supplies would not be expected to be so corrosive.

By properly applying the best current engineering design knowledge and practices for GAC systems, these rather serious problems might be avoided.

Extrapolating industrial and wastewater data to water supply. Caution must be observed in extrapolating GAC cost data from operating industrial installations and municipal wastewater treatment plants for use in the design of water treatment plants. The purpose for using GAC in each of these types of applications is generally the same—to remove organics. However, important differences exist.

In industry, GAC removes a limited group of organics—color molecules—from viscous liquid. In wastewater treatment, the GAC removes (with or without biological activity) a broad spectrum of organic substances from water as measured by biochemical oxygen demand, COD, and total organic carbon. In water treatment, the objectives of GAC treatment are not completely defined at this time. For raw waters with color or taste and odor problems, using GAC unquestionably improves drinking water from an aesthetic standpoint. In many cases, the cost of GAC may be warranted for either of these purposes alone. For the many water systems without color or taste and odor problems, the only concern with respect to organics is the possible health effects over long periods of time from ingesting trace quantities of organics that may cause cancer.

Public health officials and managers of water utilities still disagree about whether the health risks that may be involved in the presence of minute traces of organics in drinking water are sufficient to warrant the cost of GAC treatment. A major problem is that the potentially harmful organics in drinking water have not all been identified at this time, and many of those that have been tagged as suspect have widely different adsorptive characteristics. Some organics adsorb readily on GAC; others do not.

GAC loading rates at exhaustion of adsorptive capacity

TABLE 1 (continued)
Summary of GAC system characteristics

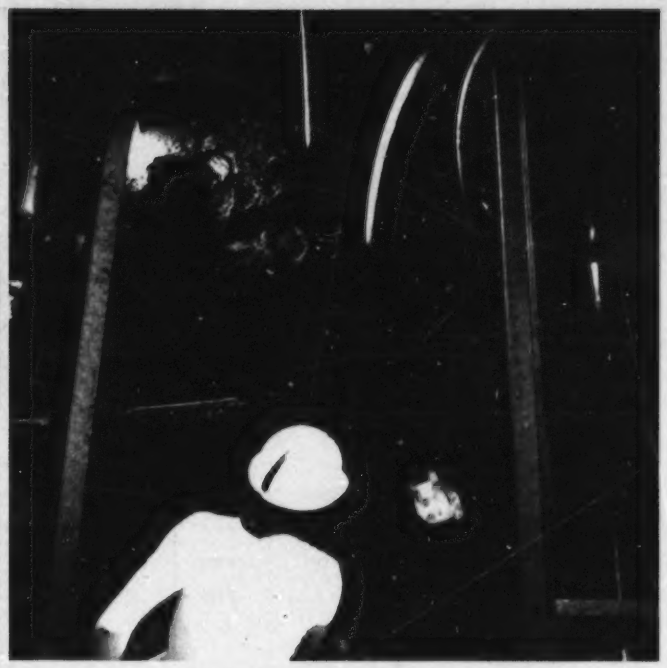
Furnace				Activated Carbon Dose			Costs				
		Fuel Use					Capital			O&M	
Carbon Loss percent	Fuel	Btu/kg carbon	Btu/lb carbon	kg/ML	lb/mil gal	kg (lb) organic/ kg (lb) carbon	dollars × 10³ (year)	dollars/kg/d of capacity	dollars/lb/d of capacity	dollars/ML	dollars/mil gal (year)
8	Gas	6 390	2 900	25	207	0.38	849 (1969)	311.95	141.50	9.53	36.07 (1979)
5	Propane	8 470	3 840			0.33	1 589 (1976)	908.77	408.59		N/A†
10	LPG	6 080	2 750	30	250	0.33	3 880 (N/A)	712.81	323.33	13.21	50.00 (1979)
9	§						N/A				N/A
7.5				169	1 410	0.50	4 359 (1974)	331.37	150.31		N/A
6	Natural gas	12 300	5 600			1.70	3 307 (1972)	807.54	275.58	23.91	90.49 (1979)
							N/A				N/A
5							N/A				N/A
5	Natural gas			120	1 000	0.26	1 000 (1971)	259.37	117.65	129.46	490.00 (1973)
8.8	Natural gas	14 300	6 500	5 150	43 000	0.38	300 (1969)	78.68	35.69	84.28	319.00 (1973)
5	Natural gas	13 700	6 200	9 470	79 000	0.26	N/A				N/A
6	LPG	13 200	6 000	59 900	500 000		225 (1973)	76.54	34.72	6 605.02	25 000 (1978)
8	Natural gas			4 190	35 000		N/A				N/A
	Fuel oil						2 500 (1975)	459.28	208.33		N/A
10	Fuel oil						N/A				N/A
10	Electricity	1.5	0.7				N/A				N/A
7.5				19	160	0.50	N/A			23.67	89.59
5	Natural gas	15 400	7 000	1 140	9 500	0.44	1 622 (1973)	106.42	48.27	388.38	1 470.00
2.5	Natural gas						N/A				N/A
							N/A			7.93	30.00 (1980)
							N/A			5.28	20.00 (1980)
4.8	Natural gas	3 940	1 785				238 (1958)	34.99	15.87		N/A

vary widely among the different potentially hazardous organics. This affects the length of service life of GAC before reactivation or replacement is necessary—a determining factor in GAC treatment costs. Similarly, the reactivation times and temperatures for thermal reactivation of GAC saturated with different organics also differ, and all are not known at this time. Again, this has an important bearing on GAC treatment costs. Because of the widely varying adsorptive and reactivation characteristics of trace organics on GAC in water supplies, pilot-plant tests of both adsorption and reactivation are currently mandatory preludes to treatment system design.

Over a period of years, average design parameters may emerge from the results of pilot-plant studies and demonstration projects, but this time is not yet at hand. Once the GAC design parameters for water treatment have been established from pilot tests for a particular water source, then the knowledge and experience from other GAC installations in industry and wastewater plants can be used. Dosages, contact times, and reactivation times and temperatures can be determined. Contactor sizes can be calculated, and furnace sizes and fuel requirements can be determined. Transport facilities for GAC in water treatment can be the same as those for other types of GAC installations provided the differences in quantities and possible differences in the viscosities of activated carbon slurries are taken into account. Also, with GAC design parameters pinpointed as a result of pilot-plant studies, construction costs can be accurately estimated based on the costs of existing installations in advanced waste treatment and industry. However, the estimates cannot be based on a capacity of megalitres per day; rather, they must be based on adsorption and reactivation data applicable to each specific installation.

Selecting the most economical number of contactors for a water system involves the same principles used for other systems. Because of shipping regulations, factory-fabricated contactor vessels are generally limited to a maximum diameter of approximately 3.6 m (12 ft). For large-capacity installations, fewer field-erected steel vessels or poured-in-place concrete vessels may be less costly.

Because upflow contactors provide all of the advantages of countercurrent operation with respect to GAC savings, they are favored for most types of service. The exception is water treatment. In this case, downflow or



A supply of granular activated carbon (top right) is mixed with water (top left) for pumping into the filter beds (bottom left).

PHOTOS COURTESY OF CALGON CORP.

upflow-downflow contactors are used to avoid the discharge of carbon fines in the effluent (a characteristic of upflow columns).

Cost estimates must be evaluated on the same basis as all other estimates of construction cost; they should not be more or less accurate than estimates made for the rest of the treatment plant. Fifteen percent is generally accepted as an allowable difference between costs estimated from construction plans and the best bid received from contractors. With good pilot-plant data and with proper application of cost data from existing GAC installations, preliminary cost estimates for GAC treatment of public water supplies should be accurate enough for planning purposes.

The extrapolation of wastewater treatment experience with GAC to the design of water treatment systems is a task for trained, experienced, engineering professionals. Even then, the following discussions are intended to be no more than an introduction to the subject.

Designing GAC systems for water treatment

The following discussion is devoted to some of the procedures and details for developing the designs and costs for GAC water treatment systems from pilot-plant test results and information from full-scale applications.

GAC system components. Systems utilizing GAC are rather simple. In general, they provide for (1) contact between the GAC and water to be treated for the length of time required to obtain the necessary removal of organics, (2) reactivation or replacement of spent carbon, and (3) transport of makeup or reactivated carbon into the contactors and transport of spent carbon from the contactors to reactivation or hauling facilities.

Pilot-plant tests. Despite the simplicity of GAC systems, laboratory and pilot-plant tests are needed to select the carbon and the most economical plant design for both water and wastewater treatment projects. Pilot column tests make it possible to determine treatability, to select the best carbon for the specific purpose based on performance, to determine the required empty bed contact time, to establish the required carbon dosage that along with laboratory tests of reactivation will determine the capacity of the reactivation furnace, to determine the necessary activated carbon replacement costs, and to determine the effects of influent water quality variations on plant operation. During pilot-plant testing, the influence of longer carbon contact time on reactivation frequency can be measured; these measurements allow costs to be minimized through a proper balance of these two design factors.

Design of pilot GAC columns. Detailed information, including a list of materials, on the design and construction of pilot GAC columns has been presented elsewhere.[5] That guide describes the analytic methodology for monitoring pilot column tests. It also includes data on the adsorbability of various organic compounds; data on the performance of GAC in removal of organics; information on the use of multiple-hearth, infrared, fluidized-bed, and rotary-kiln furnaces for reactivating spent GAC; and example calculations for balancing added costs of increased contact time versus savings (if any) from less frequent reactivation.

Use of GAC in water and wastewater treatment

Frequency of reactivation. One of the principal differences between costs for water and wastewater GAC treatment is the more frequent reactivation required in water purification because of earlier breakthrough of the organics of concern. In wastewater treatment, GAC may be expected to adsorb 0.13–0.24 kg (0.30–0.55 lb) COD/kg (lb) activated carbon before the GAC is exhausted. Research studies and pilot-plant tests have shown that some organics of concern in water treatment may break through at carbon loadings as low as 0.02–0.11 kg (0.05–0.25 lb) organic/kg (lb) carbon. The actual allowable carbon loading or carbon dosage for a given case must be determined from pilot-plant tests. Costs taken from wastewater cost curves, which are plots of flow in megalitres per day versus cost (capital or O&M costs), cannot be applied directly to water treatment. Allowance must be made in the capital costs for the different reactivation capacity needed and in the O&M costs for the actual amount of carbon to be reactivated or replaced.

Because the organics adsorbed from water are generally more volatile than those adsorbed from wastewater, the increased reactivation frequency resulting from lighter carbon loading may be partially offset, or more than offset, by the reduced reactivation requirements of the more volatile organics. The times and temperatures required for reactivation may be reduced because of both the greater volatility and the lighter loading of organics on the carbon.

From the experimental reactivation to date, reactivation temperatures may be less than the 898°C–954°C (1650°F–1750°F) required for wastewater carbons. The shorter reactivation times required for water purification carbons may allow the number of hearths in a multiple-hearth reactivation furnace to be reduced. Also, less fuel may be required for reactivation. These factors must be determined on a case-by-case basis.

GAC contactors. Selection of the contactor for a particular water treatment plant may be based on several considerations, including economics and the judgment and experience of the engineers. The choice would generally be made from three types of downflow vessels:

1. Deep-bed, factory-fabricated, steel pressure vessels with maximum diameters of 3.7 m (12 ft) might be used for GAC volumes of 56 to 1420 m^3 (2000 to 50 000 cu ft).
2. Shallow-bed, reinforced-concrete, gravity-filter-type boxes may be used for carbon volumes ranging from 28 to 5660 m^3 (1000 to 200 000 cu ft). Shallow beds will probably be used only when short contact times are sufficient or when long service cycles between reactivations can be expected from pilot-plant test results.
3. Deep-bed, site-fabricated, large-diameter (6–9 m [20–30 ft]), open concrete or steel, gravity tanks may be used for GAC volumes ranging from 170 to 5660 m^3 (6000 to 200 000 cu ft) or larger.

The ranges of these downflow vessels overlap, and the designer may make the final selection based on local factors, other than total capacity, that affect efficiency and cost.

The advanced waste treatment experience with GAC contactors may be applied to water purification if some differences in requirements are taken into account. The required contact time must be determined from pilot-plant test results. Although contactors may be designed for a downflow or upflow mode of operation and upflow packed beds or expanded beds provide maximum carbon efficiency through the use of countercurrent flow principles, the leakage of some carbon fines (1 to 5 mg/L) in upflow column effluent makes downflow or series upflow-downflow beds the preferred choices in most municipal water treatment applications. At one advanced waste treatment plant, upflow beds were converted to downflow beds to correct a problem with escaping carbon fines. This full-scale plant operating experience indicates that leakage of carbon fines is not a problem in properly operated downflow GAC contactors.

Single beds or two beds in series may be used. Open gravity beds or closed pressure vessels may be used. Structures may be properly protected steel or reinforced concrete. In general, small plants will use steel, and large plants will use steel or reinforced concrete.

Sand in rapid filters has, in some instances, been replaced with GAC. For situations in which contact times are short and GAC reactivation or replacement cycles are exceptionally long (several months or years, as may be the case in taste and odor removal), this may be a solution. With the short cycles anticipated for most organics, however, conventional concrete-box-style filter beds may not be well suited to GAC contact. Deeper beds may be more economical in first cost and provide more efficient use of GAC. In converted filter boxes, possible corrosive effects of GAC on existing metals, such as surface wash equipment and metal nozzles in filter bottoms, must be taken into account. Beds deeper than conventional filter boxes or contactors with greater aspect ratios of depth to area provide much greater economy in capital costs. The contactor cost for the needed volume of carbon is much less. In a water slurry, carbon can be moved from contactors with conical bottoms easily and quickly and with virtually no labor. Flat-bottomed filters of a type that require labor to move the carbon add unnecessarily to carbon transport costs. The labor required to remove carbon from the flat-bottomed beds varies considerably in existing installations, depending on the design of the evacuation equipment.

For many GAC installations intended for precursor organic removal or synthetic organic removal, specially designed GAC contactors should be installed.

Contactors should be equipped with flow measuring devices. Separate GAC contactors are especially advantageous when GAC treatment is required only seasonally because they can then be bypassed when not needed, possibly saving unnecessary exhaustion and reactivation of GAC.

Tremendous cost savings can be realized in GAC treatment of water through proper selection and design of the contactors. The design of contactor underdrains requires expert attention.

GAC contactor underdrains. Although proven underdrain systems are available, often they have not been used, and numerous underdrain failures have been caused by poor design. Some of the designs used in the past have failed in many installations for conventional filter service, and they continue to be misapplied to GAC contactors as well as filters.

GAC reactivation or replacement. Spent carbon may be removed from contactors and replaced with virgin carbon, or it may be reactivated either on site or off site. The most economical procedures depend on the quantities of GAC involved. For larger volumes, on-site reactivation is the answer. For small quantities, replacement or off-site reactivation will probably be most economical.

GAC may be thermally reactivated to obtain approximately original activity. However, burning losses may be excessive under these conditions. Experience in industrial and wastewater treatment indicates that carbon losses can be minimized (held to 8–10 percent per cycle).

Thermal reactivation equipment. GAC may be reactivated in a multiple-hearth furnace, a fluidized-bed furnace, a rotary kiln, or an electric-infrared furnace. Spent GAC is drained dry in a screen-equipped tank (40 percent moisture content) or in a dewatering screw (40–50 percent moisture) before being introduced to the reactivation furnace. Dewatered carbon is usually transported by a screw conveyor. Following thermal reactivation, the GAC is cooled in a quench tank. The water-carbon slurry may then be transported by means of diaphragm slurry pumps, eductors, or a blow tank. The reactivated carbon may contain fines produced during conveyance. These fines should be removed in a wash tank or in the contactor. Maximum furnace temperatures and retention time in the furnace are determined by the amount and nature of the organics adsorbed.

Exhaust gases from the reactivation process present no air pollution problems if they are properly scrubbed. In some cases, an afterburner may also be required for odor control.

Despite recent advances in the design of infrared and fluidized-bed reactivation furnaces, the multiple-hearth furnace is still the simplest, most reliable, and easiest to operate for GAC reactivation. Problems with the infrared and fluid-bed units have yet to be solved; experience with the multiple-hearth equipment has already solved these problems. Still, it is necessary to specify top-quality materials to suit the conditions of service for each type of furnace and to see that these materials are properly installed. Corrosion resistance is important in the furnace itself and especially in all auxiliaries to the furnace.

Required furnace capacity. The principal cost differences between GAC treatment of water and wastewater may be in the capital cost of the furnace and in the O&M cost for carbon reactivation. As already explained, the two principal differences between carbon exhausted in wastewater treatment and carbon exhausted in water purification are that water purification carbons are likely to be easier to reactivate (less time in furnace and lower furnace temperatures) and more lightly loaded (greater volume of carbon to be reactivated per amount of organics removed). Accurate estimates of GAC costs require knowledge and consideration of both of these factors. To repeat, it is not possible to use advanced waste treatment cost curves based on daily flow (megalitres per day) or plant capacity to obtain costs for water treatment. Differences in reactivation requirements must be taken into account.

Transport and GAC process auxiliaries. The large differences in O&M costs for GAC systems depend on the method selected for carbon transport. Hydraulic transport of GAC in water slurry by gravity or water pressure is simple, easy, inexpensive, and rapid and uses little labor. Moving dry or dewatered activated carbon manually or mechanically can be difficult, time-consuming, and costly.

Cost of GAC in water treatment

Developing cost curves. Little information is available concerning the cost and performance of GAC for drinking water treatment. As discussed in the previous sections, most of the data available on GAC performance have been acquired from wastewater and industrial applications. An attempt has been made, however, to extrapolate information from these existing systems and to develop standardized and flexible cost data that can be used to prepare cost estimates for GAC systems that treat drinking water.

Much of the analysis and cost information contained in this article is based on previous work[1-4] in which 12 cost curves were developed specifically for GAC applications.

The construction cost for each unit process was presented as a function of the process design parameter. This parameter was determined to be the most useful and flexible under varying conditions, such as loading rate, detention time, or other conditions that vary because of designer's preference or regulatory agency requirements. For example, the cost curves for contactor construction were presented in terms of contactor volume, an approach that allows various empty bed contact times to be used. Contactor O&M curves were presented in terms of surface area, because O&M requirements are more appropriately related to surface area than to contactor volume. Reactivation-facility cost curves were presented in terms of surface area of hearth for the multiple-hearth furnace and mass per day of reactivation capacity for the other reactivation variables. This allows the loading per unit of hearth surface area to be varied for the multiple-hearth furnace and for design of reactivation furnaces at rates less than the reactivation capacity. This approach provides greater flexibility in the use of the cost curves than if the costs were related to water flow through the treatment plant.

For the majority of the unit processes, three separate figures were used to present construction and O&M curves. The first graph presented the construction cost; the second graph, energy (electrical, natural gas, and diesel fuel) and maintenance material requirements; and the third graph, labor requirements and total O&M cost.

Two major and separate process operations are involved in GAC treatment of water: filtration and reactivation. The water comes in contact with GAC by passing

through a structure filled with activated carbon granules. Impurities are removed from the water by adsorption when sufficient time is provided for this process. The structure can be either a water treatment filter shell in which the filter media has been replaced with GAC or an independent carbon adsorption system. A separate adsorption system usually consists of several columns or basins, used as contactors, that are connected to a reactivation system. After a period of use, the GAC's adsorptive capacity is exhausted, and the GAC must then be taken out of service. The spent GAC is either replaced with new carbon or reactivated by combustion of the organic adsorbate. Carbon is routinely added to the system to replace that lost during hydraulic transport and reactivation. These losses are caused by physical deterioration and by burning during the reactivation process.

Cost estimates have been prepared for the use of GAC as a replacement for existing filtration media (sand replacement) and as a separate adsorption system (postfilter adsorption). On-site multiple-hearth reactivation was assumed. Standard levels of key design parameters were set at predetermined levels, and then one variable at a time was changed to determine its effect on system cost. Figure 1 shows the cost of both sand replacement and postfilter adsorption systems versus plant capacity.

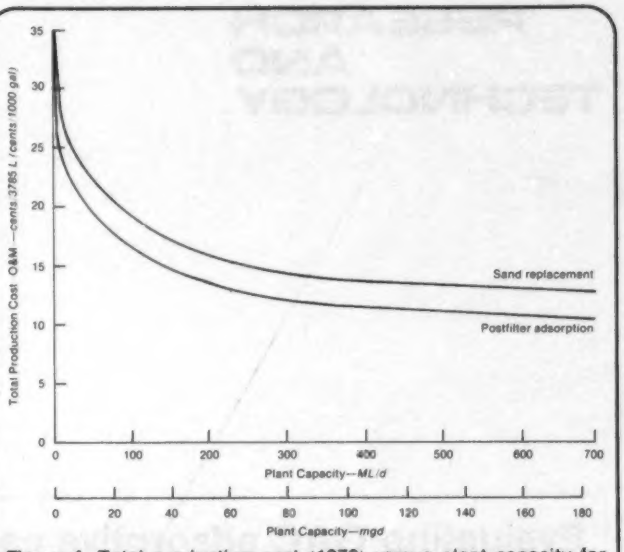


Figure 1. Total production cost (1979) versus plant capacity for postfilter adsorption and sand replacement systems

Conclusions

Several conclusions can be drawn from the inspection of 22 operating GAC adsorption and reactivation systems and a study of the costs involved:

1. A substantial number of GAC installations have been operating successfully for many years. These installations include facilities for treating water and wastewater and for processing food and drink.
2. Although long-term use of GAC and PAC by water utilities and industries has been widespread, no adverse health effects have been reported.
3. Treating public water supplies with GAC to remove trace organics is fairly new. Only limited direct design data or cost information are available.
4. The use of GAC in treating water supplies for taste and odor control or color removal is practiced in about 46 cities in the United States. In this application of GAC, however, there is little need for reactivation, and little experience with on-site reactivation exists.
5. The USEPA is currently sponsoring four reactivation studies that will soon yield performance and cost data for GAC systems at water supply installations. These studies are located in Cincinnati, Ohio; Manchester, N.H.; Jefferson Parish, La.; and Passaic Valley, N.J.
6. Information from 20-30 GAC installations in food (corn syrup and beet sugar) processing plants gives insight concerning the safety of GAC from a public health standpoint but adds little to the available cost data. Some design ideas and information can be obtained from these sources.
7. Experience with 20-30 GAC reactivation furnaces in industrial water pollution control plants yields some information on the operation and cost of GAC systems.
8. The best sources of detailed cost information and equipment design data are the 20 or so municipal advanced waste treatment plants that use GAC.
9. Pilot-plant testing of GAC adsorptive and reactivation characteristics in municipal water treatment plants can be properly combined with the known costs of GAC systems in wastewater treatment to yield designs and preliminary cost estimates that are satisfactory for developing water treatment projects. Designers should take full advantage of available information regarding GAC use in municipal water treatment for taste and odor control, municipal advanced waste treatment, industrial wastewater treatment, and food and pharmaceutical production.

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